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Measuring Technical Change and Productivity Growth with Varying Output Qualities and Incomplete Panel Data*

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ABSTRACT

This paper presents a method for estimating technical change using incomplete panel data. In addition, we show how estimates of cost elasticities with respect to output qualities can be used to evaluate productivity growth adjusted for quality changes. In order to control for the incomplete nature of the sample used, specific dummy variables for entry in and exit from the sample are introduced into the cost function. The proposed methodology is applied to a sample of trucking firms from Quebec. Results show that without correction for sample entry or exit, the estimated rate of technical change between 1987 and 1988 is -29.7%. When entry in or exit from the sample is taken into account, the estimated rate is -4.2%. Also, during the same period, the observed TFP growth rate is 63.4%. After adjustment for quality changes, this rate falls to -4.6%.

Keywords: technical change, productivity, panel data, trucking.

RÉSUMÉ

Dans cet article, nous proposons une méthodologie permettant l'estimation du progrès technique avec un échantillon incomplet de firmes. Également, nous montrons comment les valeurs estimées des élasticités des coûts par rapport aux variables de qualité de la production peuvent être utilisées afin d'épurer le taux de croissance observé de la productivité des effets des changements de qualités. Afin d'estimer le progrès technique, nous introduisons dans la spécification de la fonction de coût des variables binaires spécifiques à l'entrée et à la sortie d'une firme de l'échantillon. Notre méthodologie est l'objet d'une application à un échantillon (incomplet) d'entreprises québécoises de transport par camion. Nos résultats montrent que sans correction pour l'entrée et la sortie de firmes de l'échantillon, le taux de progrès technique estimé se situe à -29,7% entre 1987 et 1988. Le même taux corrigé est de -4,2%. De plus, au cours de la même période, le taux de croissance observé de la productivité est de 63,4%. Après correction pour les changements de qualité, le taux se situe à -4,6%.

Mots-clés: progrès technique, productivité, données de panel, camionnage.

1. Introduction

There exists two approaches to the measurement of technical change[1]. The first one, which does not involve any econometric estimation, must assume a constant returns to scale technology. In that case, it can easily be shown that technical change is equivalent to productivity growth as measured by an index of total factor productivity (TFP) growth (see, for instance, Denny, Fuss and Waverman, 1981). Besides constant returns to scale, it is also implicitly assumed that the qualities of the output produced with the technology under study have not experienced important changes over time. Otherwise, productivity gains or losses cannot be correctly identified with existing indexes of TFP[2]. In several sectors of the economy, qualities of output or, in a more general term, technological characteristics, vary significantly over time or between firms. For example, in the transportation sector, technological characteristic variables are used in empirical analyses to control the network of the firms. Network attributes could experience very large variations for a given firm over time or could be very different between firms. Large variations of technological characteristics could be interpreted as variations of productivity. These variations must therefore be taken into account when evaluating productivity growth and technical change.

In the second approach, technical change and, ultimately, productivity growth are evaluated from the parameter estimates of a cost function which includes technological characteristic variables. This econometric approach implies three fundamental

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[1] That is, change in the "frontier" of production.

[2] Also, productivity comparisons cannot be made between economic units such as firms if the qualities of output are different between units. See Gordon (1991) for a similar discussion on analyses of aggregate productivity growth.

assumptions: technical efficiency (all the observations are lying on the frontier of production), allocative efficiency (exact cost minimization) and perfect competition in the factor markets. Moreover, identification of the rate of productivity growth or comparison of productivity levels also requires constant qualities of output over time or between firms.

In addition to these assumptions and according to the current trend in the literature, cost function estimates must rely on a complete panel data set of firms. Hence, the econometric approach to the measurement of technical change and productivity growth is applied to complete data sets, that is, time series of firms or panel data sets which contain the same sample of firms over several periods (usually years). The reason for this practice is that the use of incomplete panel data without an appropriate methodology could result in incorrect evaluations of technical change as measured by shifts of the cost function, since these shifts could also be attributable to changes in the sample of firms over time.

Most panel data sets of firms that are available are incomplete. In order to estimate the rate of technical change and productivity growth, a complete panel data set is often created from an incomplete one. Obviously, this practice may result in serious selection bias if firms which are not in the sample during the whole period under study share some special characteristics that distinguish them from the others. In such a case, empirical evaluations of technical change and productivity may be biased.

Furthermore, the use of a complete data set could be troublesome to analyze the effects of economic deregulation on technical change, productivity and costs of firms.

In fact, one of the main effects of economic deregulation is to alter the structure of an industry by potentially causing a high level of entry and exit activity. Therefore, any analysis of the effects of deregulation must take into account these entry and exit movements to obtain a complete picture of the situation. For instance, Ying (1990) has evaluated that the cumulative effects of deregulation in the U.S. trucking industry have led to a 1% increase in costs in 1981 (an early stage of deregulation) and a 16% increase in productivity in 1984, when using a complete panel data set of firms. However, even if Ying's figures could be considered as valid for the firms in his sample, they could not be applied to the entire industry since his data set does not consider exiting and, especially, entering firms[3].

Panel data sets of firms actually available are incomplete not only because of entry in or exit from the industry, but also because information on all firms is not available over the entire period under study. In most cases, the agency collecting the data did not survey a firm for several years. It is also possible that the data collected cannot be used because of inaccuracies or because some values are missing. Sample entry and exit movements could therefore be attributable to entry in and exit from the industry or to other unrelated factors. However, accurate measurement of technical change, as stated above, can only be realized with all the data available and not only with firms which are in the sample for the entire period studied. In our empirical application, entry and exit movements of the firms in the sample could be explained by entry in and exit from the industry as well as by the other factors mentioned above.

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[3] In fact, Winston et al. (1990) report a large number of entry and exit movements of trucking firms following the 1980 deregulation.

The object of this paper is to present a method for estimating technical change using incomplete panel data. In addition, we show how estimates of cost elasticities with respect to technological characteristics can be used to evaluate productivity growth adjusted for characteristic changes. Our method can be used when technical change is taken into account by introducing a time trend into the cost function or a more general index, as proposed recently by Baltagi and Griffin (1988). In our empirical application, we shall use the Baltagi and Griffin index. The proposed method can be extended to a sample of firms covering a long period of analysis, even if no individual firm is in the sample over the entire period. This particularity of the method provides an answer to the criticism that studies based on individual carrier data are limited to short sample periods (Gordon, 1991).

The proposed method is applied to measure technical change and productivity growth in the Quebec trucking industry between 1981 and 1988. Mainly two reasons have motivated the choice of this particular industry for our application. Trucking firms operate over a network and this specificity is taken into account by introducing technological characteristic variables into the cost function[4]. This will permit the evaluation of productivity growth of firms for a given network.

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[4] This is a common and recognized practice in the continual developing field of cost and production structure analyses of the trucking industry. See Spady and Friedlaender (1978, 1981), Friedlaender and Wang Chiang (1983), Kim (1984), Friedlaender and Schur Bruce (1985), Daughety, Nelson and Vigdor (1985), Daughety and Nelson (1988), Gagné and Dionne (1988) and Ying (1990). In addition, Gagné (1990) discusses the interpretation that should be given to the technological characteristics in terms of the cost elasticities with respect to those characteristics. In other fields of application see, for instance, Braeutigam and Pauly (1986) for automobile insurance and Fuss and Waverman (1981) for telecommunications.

Moreover, the Quebec trucking industry has experienced significant regulatory changes during the 80's (notably in 1984 and 1988), and these changes may have caused some impact on technical change, productivity and, ultimately, on costs of trucking firms. Estimates of productivity growth could be used to evaluate the economic performance of trucking firms during the transition to deregulation, while estimates of technical change could tell us how a more competitive environment incites firms to adopt a more (less) advanced technology. Finally, our sample of firms is incomplete for several reasons[5]. Any attempt to build a complete (balanced) data set with our sample would result in a data set containing only a few firms[6].

The paper is organized as follows. In section 2, we review the economic theory underlying the measurement of technical change and productivity for a technology producing output with different characteristics. Section 3 presents the methodology proposed to empirically evaluate technical change and productivity growth with incomplete panel data and technological characteristic changes. This methodology is then applied to an incomplete panel data set of Quebec trucking firms. The econometric results are presented in section 4. Concluding comments are discussed in the last section.

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[5] Entry in or exit from the industry and missing information on some or all variables.

[6] The incomplete data set contains 358 observations, while a complete data set would contain only 48 observations (6 firms, 8 years).

2. Measuring Technical Change and Productivity Growth with Varying Output Qualities

2.1 Technical Change

Technical change basically means shifts in the production function over time. Following Denny et al. (1981), let us consider the following production function:

$$y = f(x, q, A), \tag{1}$$

where y is the output, $y = y(t)$, t represents time, $t = 1, ..., T$, x is a vector of input quantities $(x_1, ..., x_m, ..., x_M)$, $x_m = x_m(t)$, q is a vector of technological characteristics $(q_1, ..., q_u, ..., q_U)$, $q_u = q_u(t)$, A is an index of technical change, $A = A(t)$ and $f(x, q, A)$ is at least twice continuously differentiable, decreasing in q and increasing and concave in x. These assumptions mean, among other things, that for a given quantity of inputs more quality (as measured by q) leads to less output, or that for a given output, more quality needs more inputs.

Technical change may be measured by the proportional variation of y following a variation of A such that equation (1) still holds for a given quantity of inputs x and technological characteristic levels q. Taking the total differential of (1) with respect to time (holding x and q constant) yields

$$\dot{T} = \frac{\partial f(x, q, A)}{\partial A} \frac{1}{f(x, q, A)} (A(t) - A(t-1)), \tag{2}$$

where $\dot{T} \equiv \frac{dy}{dA} \frac{1}{y} (A(t) - A(t-1))$ is the rate of technical change, i.e. the proportional variation of y when A is changing through time.

From (2), we see that technical change is measured by the proportional shift of the production function if $f(x, q, A)$ is known. However, in most cases $f(x, q, A)$ is

unknown and so is its functional form. One must therefore specify a particular form for the production function and estimate it by an appropriate econometric method. Direct estimation of the production function assumes implicitly that the input quantities x are exogenous and independently chosen. Otherwise, the econometric estimation of the production function is inappropriate.

In order to avoid this difficulty, we can use duality and define technical change in terms of a cost function. A cost function gives the minimum cost of producing y, given the input prices w, the characteristics q and the state of the technology represented by A, i.e.

$$c(y,w,q,A) \equiv \min_{x} \left\{ \sum_{m=1}^{M} w_m x_m : \; y = f(x,q,A) \right\}, \tag{3}$$

where w_m is the price of input m, $w_m = w_m(t)$. The cost function $c(y,w,q,A)$ is increasing in y, q and w as well as homogeneous of degree one and concave in w.

From the envelope theorem we obtain

$$\frac{\partial c(y,w,q,A)}{\partial y} = \lambda^*, \tag{4}$$

and

$$\frac{\partial c(y,w,q,A)}{\partial A} = -\lambda^* \frac{\partial f(x^*,q,A)}{\partial A}, \tag{5}$$

where λ is the Lagrangean multiplier and a star indicates an optimizer. Therefore,

$$-\frac{\partial c(y,w,q,A)}{\partial A} \Big/ \frac{\partial c(y,w,q,A)}{\partial y} = \frac{\partial f(x^*,q,A)}{\partial A}, \tag{6}$$

and, in the dual space, the rate of technical change is given by

$$\dot{T} = -\frac{\dot{G}}{\varepsilon_y}, \tag{7}$$

where $\varepsilon_y \equiv \frac{\partial \ln c(y,w,q,A)}{\partial \ln y}$ and $\dot{G} \equiv \frac{\partial \ln c(y,w,q,A)}{\partial A}(A(t) - A(t-1))$.

The rate of technical change is equivalent to the shifts of the cost function adjusted by the elasticity of costs with respect to output. For a constant returns to scale technology, this elasticity is equal to 1 and the rate of technical change is exactly measured by the shifts of the cost function.

2.2 Productivity Growth

Productivity is a ratio of output to input and productivity growth is measured by the difference between the rate of growth of the output and the rate of growth of the input. When more than one input is used, the concept of productivity is replaced by the more general concept of total factor productivity (TFP) where all the inputs are aggregated into a single index. Hence, the observed TFP growth is defined as

$$\dot{TFP} = \dot{y} - \dot{x}, \tag{8}$$

where $\dot{y}$ is the rate of growth of output and $\dot{x}$ is an aggregated index of the rates of growth of inputs. The most widely used method of aggregation in productivity analysis is the Divisia aggregation. The Divisia index for aggregate inputs is

$$\dot{x} = \sum_{m=1}^{M} \frac{w_m x_m}{C} \dot{x}_m, \tag{9}$$

where $\dot{x}_m$ is the rate of growth of input m and $C = \sum_{m=1}^{M} w_m x_m$.

When the firms are cost minimizing, it is easy to relate the observed TFP growth as measured by (8) to the rate of technical change. Since $\sum_{m=1}^{M} w_m x_m = c(y,w,q,A)$, totally differentiating with respect to time and rearranging yield

$$\dot{x} = \varepsilon_y \dot{y} + \dot{G} + \sum_{u=1}^{U} \varepsilon_{q_u} \dot{q}_u, \tag{10}$$

where ε_{q_u} is the elasticity of costs with respect to quality u and $\dot{q}_u$ is the rate of growth of characteristic u. Using (8) and (10), the observed TFP growth may be written as

$$T\dot{F}P = (1 - \varepsilon_y)\dot{y} - \dot{G} - \sum_{u=1}^{U} \varepsilon_{q_u}\, \dot{q}_u. \tag{11}$$

Applying duality principles, we see from (11) that the observed TFP growth could be divided into three components: scale effect, technical change and technological characteristic effect. Therefore, if technological characteristics experience important changes during the period under study, these changes may in turn influence the observed TFP growth. Equation (11) also indicates that technical change is exactly measured by the observed TFP growth under constant returns to scale and constant characteristics. If this is not the case, technical change may be estimated by using the parameters of the cost function according to equation (7).

In addition, by setting $\dot{q}_u = 0$, $u = 1, ..., U$, the observed TFP growth is adjusted for technological characteristic changes and the resulting rate represents the TFP growth with constant characteristics. In fact, this adjusted TFP growth is computed with a corrected index of inputs

$$\dot{x}^* = \dot{x} - \sum_{u=1}^{U} \varepsilon_{q_u}\, \dot{q}_u, \tag{12}$$

and the adjusted TFP growth is

$$T\dot{F}P^* = \dot{y} - \dot{x}^*. \tag{13}$$

This approach to the adjustment of TFP growth for technological characteristic variations assumes that the elasticities of costs with respect to these characteristics are known. Moreover, the adjustment is done through the inputs. This means that the adjusted TFP growth is evaluated by the difference between the rate of growth of output and the rate of growth of inputs that would have been observed with constant technological characteristics[7].

3. Empirical Specification

In order to properly evaluate the rate of technical change and also obtain estimates of cost elasticities with respect to output and technological characteristics, we must first assume a specific functional form for $c(y, w, q, A)$. Since we do not have any a priori knowledge of the technology, $c(y, w, q, A)$ is approximated by a translog form which represents a second-order Taylor series approximation to an unknown function. In addition, following Baltagi and Griffin (1988), we replace the standard time trend with an unobserved general index of technical change A. However, let us emphasize that two significant aspects distinguish our empirical model. Technological

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[7] Alternatively, the observed TFP growth could be adjusted through the output. In this case, the adjusted TFP growth is evaluated by the difference between the rate of growth of output (that would have been observed with constant technological characteristics) and the observed rate of growth of inputs. Hence, using (10) we have that

$$\dot{y} = \frac{\dot{z} - \dot{G} - \sum_{u=1}^{U} \varepsilon_{q_u} \dot{q}_u}{\varepsilon_y}.$$

By setting $\dot{q}_u = 0$, $u = 1, ..., U$, the rate of growth of output with constant technological characteristics is $\dot{y}^* = \frac{\dot{z} - \dot{G}}{\varepsilon_y}$, and the adjusted TFP growth is given by $\dot{y}^* - \dot{z}$. This alternative approach is, however, inconsistent with the assumption that firms choose input quantities according to output level and technological characteristics.

characteristics (q) are explicitly introduced in the model and, as we will show below, the rate of technical change will be estimated by using specific entry and exit dummies. The translog form of $c(y, w, q, A)$ is given by

$$
\begin{aligned}
\ell n\, c(y,w,q,A) = & \sum_{t=1}^{T} \gamma(t)\, D(t) \\
& + \sum_{t=1}^{T} \omega(t)\, D(t)\, \ell n(y/\bar{y}) \\
& + \sum_{t=1}^{T} \sum_{m=1}^{M} \sigma_m(t)\, D(t)\, \ell n(w_m/\bar{w}_m) \\
& + \sum_{t=1}^{T} \sum_{u=1}^{U} \rho_u(t)\, D(t)\, \ell n(q_u/\bar{q}_u) \\
& + \frac{1}{2}\, b_{yy} (\ell n(y/\bar{y}))^2 \\
& + \frac{1}{2} \sum_{m=1}^{M} \sum_{s=1}^{M} c_{ms}\, \ell n(w_m/\bar{w}_m)\, \ell n(w_s/\bar{w}_s) \\
& + \frac{1}{2} \sum_{u=1}^{U} \sum_{v=1}^{U} d_{uv}\, \ell n(q_u/\bar{q}_u)\, \ell n(q_v/\bar{q}_v) \\
& + \sum_{m=1}^{M} f_{ym}\, \ell n(y/\bar{y})\, \ell n(w_m/\bar{w}_m) \\
& + \sum_{u=1}^{U} g_{yu}\, \ell n(y/\bar{y})\, \ell n(q_u/\bar{q}_u) \\
& + \sum_{m=1}^{M} \sum_{u=1}^{U} h_{mu}\, \ell n(w_m/\bar{w}_m)\, \ell n(q_u/\bar{q}_u),
\end{aligned}
\tag{14}
$$

where $D(t) = 1$ at period t $(D(t) = 0,$ otherwise) and the bar stands for the arithmetic mean of the variables which represents the point of approximation. The

usual symmetry and homogeneity restrictions should be imposed on (14) prior to its estimation. Furthermore, using Shephard's lemma, the input share equations are

$$\frac{w_m\, x_m}{C} = \sum_{t=1}^{T} \sigma_m\, D(t) + \sum_{s=1}^{M} c_{ms}\, \ell n(w_s/\overline{w}_s) + f_{ym}\, \ell n(y/\overline{y}) + \sum_{u=1}^{U} h_{mu}\, \ell n(q_u/\overline{q}_u),\ m = 1, ..., M. \tag{15}$$

The usual procedure is to estimate jointly the cost function and its corresponding input share equations using the iterative version of the Zellner (1962) method[8]. Moreover, since input shares add up to 1, an input share equation is deleted in order to avoid the singularity of the estimated disturbance covariance matrix.

In order to estimate the rate of technical change we further specify

$$\begin{aligned}
&\gamma(t) = a_o + A(t) + \alpha(t)\, DE(t) + \beta(t)\, DX(t),\\
&\omega(t) = b_y + \phi_y\, (A(t) + \alpha(t)\, DE(t) + \beta(t)\, DX(t)),\\
&\sigma_m(t) = c_m + \psi_m\, (A(t) + \alpha(t)\, DE(t) + \beta(t)\, DX(t)),\ m = 1, ..., M,\\
&\rho_u(t) = d_u + \mu_u\, (A(t) + \alpha(t)\, DE(t) + \beta(t)\, DX(t)),\ u = 1, ..., U,
\end{aligned} \tag{16}$$

where $a_o, b_y, c_m, d_u, \phi_y, \psi_m, \mu_u, \alpha(t), \beta(t)$ and $A(t)$ are parameters; $DE(t) = 1$ if the firm is not in the sample in $t-1$, $DE(t) = 0$, otherwise; $DX(t) = 1$ if the firm is not in the sample in $t+1$, $DX(t) = 0$, otherwise. The index of technical change $A(t)$ is a parameter to be estimated. To identify $A(t)$ as well as $a_o, b_y, c_m, d_u, \phi_y, \psi_m, \mu_u, \alpha(t)$, and $\beta(t)$, we set $A(1) = 0$. Also, since we will not allow entry and exit in the first and last periods, we set $\alpha(1) = \beta(1) = \alpha(T) = \beta(T) = 0$. When a complete panel data

[8] Specifically here, since the model is nonlinear in the parameters, we use the iterative version of the nonlinear seemingly unrelated regression method.

set is used ($DE(t) = DX(t) = 0$ for $t = 1, ..., T$) and technological characteristics are not explicitly considered, our model is equivalent to that of Baltagi and Griffin.

Equation (16) defines the additive specification. With this specification, entry in and exit from the sample may affect technical change through the index $A(t)$. Thus, $\alpha(t)$ and $\beta(t)$ isolate the effects that entry and exit may have on $A(t)$ which implies that $A(t)$ can be used to evaluate technical change with an incomplete panel data set. In the empirical analysis, we will also present the results obtained with the following multiplicative specification:

$$\begin{aligned}
&\gamma(t) = a_o + A(t)\,(1 + \alpha(t)\,DE(t) + \beta(t)\,DX(t)),\\
&\omega(t) = b_y + A(t)\,(\phi_y + \alpha(t)\,DE(t) + \beta(t)\,DX(t)),\\
&\sigma_m(t) = c_m + A(t)\,(\psi_m + \alpha(t)\,DE(t) + \beta(t)\,DX(t)),\ m = 1, ..., M,\\
&\rho_u(t) = d_u + A(t)\,(\mu_u + \alpha(t)\,DE(t) + \beta(t)\,DX(t)),\ u = 1, ..., U.
\end{aligned} \tag{17}$$

This alternative specification allows for the correction of the effects of entry and exit on $\frac{\partial\, ln\, c(y,w,q,A)}{\partial A}$ rather than on $A(t)$. Here, entry in or exit from the sample may have an impact on the way $A(t)$ is affecting total costs.

Using the parameter values obtained from the estimation of the model defined by (14), (15) and (16), the estimated rate of technical change is computed by[9]

$$\dot{T}(E) = -\frac{1+\hat{\phi}_y\, ln(y/\overline{y})+\sum_{m=1}^{M}\hat{\psi}_m\, ln(w_m/\overline{w}_m)+\sum_{u=1}^{U}\hat{\mu}_u\, ln(q_u/\overline{q}_u)}{\hat{\varepsilon}_y}\left(\hat{A}(t)-\hat{A}(t-1)\right) \tag{18}$$

where

[9] An equivalent equation for the multiplicative specification can be derived.

$$\hat{\varepsilon}_y = \sum_{t=1}^{T} \left(\hat{b}_y + \hat{\phi}_y \left(\hat{A}(t) + \hat{\alpha}(t)\, DE(t) + \hat{\beta}(t)\, DX(t) \right) \right) D(t)$$

$$+ \hat{b}_{yy}\, \ell n(y/\overline{y}) + \sum_{m=1}^{M} \hat{f}_{ym}\, \ell n(w_m/\overline{w}_m) + \sum_{u=1}^{U} \hat{g}_{yu}\, \ell n(q_u/\overline{q}_u),$$

is the estimated value of the cost elasticity with respect to output and ˆ represents the estimated values of the parameters.

The unadjusted TFP growth is also computed as

$$T\dot{F}P(E) = (1 - \hat{\varepsilon}_y)\, \dot{y} + \dot{T}(E)\, \hat{\varepsilon}_y - \sum_{u=1}^{U} \hat{\varepsilon}_{q_u}\, \dot{q}_u, \tag{19}$$

where

$$\hat{\varepsilon}_{q_u} = \sum_{t=1}^{T} \left(\hat{d}_u + \hat{\mu}_u \left(\hat{A}(t) + \hat{\alpha}(t)\, DE(t) + \hat{\beta}(t)\, DX(t) \right) \right) D(t) + \sum_{v=1}^{U} \hat{d}_{uv}\, \ell n(q_v/\overline{q}_v)$$

$$+ \hat{g}_{yu}\, \ell n(y/\overline{y}) + \sum_{m=1}^{M} \hat{h}_{mu}\, \ell n(w_m/\overline{w}_m),\ u = 1, \ldots, U.$$

Equation (19) gives the estimated value of total factor productivity growth without adjustment for characteristic changes. This value will be compared to the observed value given by (8) in order to evaluate the ability of the empirical models to predict the observed TFP growth.

Furthermore, the estimated parameters of the cost function will be used to adjust the observed TFP growth rate for characteristic changes. Hence, using (12) and (13), we get

$$T\dot{F}P^*(E) = \dot{y} - \left(\dot{x} - \sum_{u=1}^{U} \hat{\varepsilon}_{q_u}\, \dot{q}_u \right). \tag{20}$$

4. Empirical Analysis

4.1 Data and Variables

Our data set consists of 358 observations on general freight carriers in Quebec between 1981 and 1988. This data set comes from two surveys conducted by Statistics Canada: The Motor Carrier Freight (MCF) survey and the Origin-Destination Trucking (TOD) survey. The MCF survey contains information on inputs and costs. It includes the financial statement as well as data on employment, fuel consumption, equipment, etc. The TOD survey contains a sample of shipments carried by a subset of firms of the MCF survey. For each shipment surveyed, information on the origin, the destination, the type of commodity, the weight, and the revenues generated by the shipment is available. For our analysis, we retain only firms for which general freight has accounted at least 50% of the total revenues. Our data set is incomplete since only six firms are present in the sample for the entire period (1981 to 1988). The rest of the sample is composed of firms which are present for less than 8 years.

A careful examination of the data set reveals a high level of entry and exit activity in the sample. This may be due to entry in the industry after 1981 or exit before 1988. A firm can also be missing for a year or more because it has not answered (or has improperly answered) the MCF and/or the TOD surveys. This means that $\alpha(t)$ and $\beta(t)$ cannot be interpreted as the effects of entry in and exit from the industry on the index of technical change $A(t)$ (or on $\frac{\partial \ln c(y,w,q,A)}{\partial A}$ in the multiplicative specification) since these parameters may also capture other unrelated effects.

Because computation of annual growth rates at the firm level requires information on a firm for at least two consecutive years, in our sample we have deleted those firms which do not appear at least two years in a row. Consequently, 89 observations were deleted, which left us with a sample of 269 observations for the empirical analysis.

The specific definitions of the variables included in the cost function are given as follows:

C	:	total operating costs, including a 10% opportunity cost of capital ($);
w_1	:	price of fuel, including taxes ($/litre);
w_2	:	price of labor, including fringe benefits ($/man-year);
w_3	:	price of capital, including opportunity cost ($/$ value of capital stock);
w_4	:	price of materials, a Division index of the prices of all other inputs ($);
y	:	total number of shipments;
q_1	:	average length of haul (kilometers);
q_2	:	average shipment size (tons);
q_3	:	average load per truck (ton/vehicle-kilometer);
q_4	:	insurance for loss and damage ($/ton-kilometer).

Table 1 presents the sample mean and standard deviation of these variables.

4.2 Empirical Results

In Table 2, estimation results for three different versions of equations (14) and (15) are presented. The first column of Table 2 gives the parameter estimates obtained with the additive specification (equations (16)), while in the second column the parameter

estimates of the multiplicative specification are given (equations (17)). Parameter estimates obtained under the constraint that $\alpha(t) = \beta(t) = 0$, $t = 2,...,T-1$, are presented in column 3. For the three specifications, tests for a well-behaved technology give very good results. In the three specifications, fitted shares are positive for all observations and concavity violations in w occur in only 6, 5 and 5 cases, respectively. Furthermore, using a likelihood ratio (LR) test leads to the rejection of $\alpha(t) = \beta(t) = 0$, $t = 2,...,T-1$, with the additive specification but not with the multiplicative one.[10] This result is consistent with the fact that some $\alpha(t)$ and $\beta(t)$ parameters are statistically significant in the additive specification, while they are never significant in the multiplicative model. It also indicates that entry in and exit from the sample have affected the index of technical change $A(t)$. Moreover, rejection of the multiplicative specification indicates that entry in and exit from the sample do not affect $\frac{\partial \ln c(y,w,q,A)}{\partial A}$.

Regardless of the specification employed, results always suggest that the average firm in the sample operates at increasing returns to scale since b_y ranges from 0.76 to 0.81 and is statistically different from 0 and 1 in the three cases. Therefore, the observed TFP growth cannot be used for approximating the rate of technical change for firms in this sample.

The first-order parameters of the technological characteristic variables (d_u, $u = 1,...,U$) evaluating the elasticity of costs at the point of approximation, are all

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[10] The LR statistic for the constrained version with respect to the additive specification is 19.66, which is greater than the critical value of χ^2 with 12 degrees of freedom at a 10% confidence level ($\chi^2_{12,0.1} = 18.5$). The LR statistic for the multiplicative specification is 16.75.

significant. Our results show that for a given number of shipments, a higher average length of haul, shipment size and insurance premiums for loss and damage raise costs. However, a higher average load per truck diminishes costs. Consequently, a higher load per truck means lower quality, while a higher length of haul, shipment size and insurance premiums mean higher quality (in terms of network attributes).

4.3 TFP Growth and Technical Change

The rates of growth of observed TFP have been computed using (8).[11] Annual weighted averages of these rates are presented in the first column of Table 3.[12] In the second column, the equivalent rates computed with a complete data set (6 firms) are given. The significant difference between the two sets of rates indicates that firms not in the sample in each period are different from the others in terms of their productivity growth rates. Excluding them from the analysis would create serious selectivity bias. The estimated TFP growth rates computed by equation (19) using the parameter estimates of the three specifications discussed above are shown in columns 3, 4 and 5. It seems that the type of specification does not have any important effect on estimated TFP growth. In fact, for all three specifications, the average mean square differences between observed and estimated TFP growth are approximately the same.[13]

These results are misleading because the proposed adjustment for entry in and exit from the sample does not have a big effect on estimates of cost elasticities with

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[11] Rates of growth have been calculated by using the difference in the log of the variables between t and $t-1$.

[12] The level of output y has been used for weighting.

[13] The mean square difference between observed and estimated growth rates are 0.121, 0.115 and 0.111 respectively for the additive, multiplicative and constrained specification.

respect to output ($\hat{\varepsilon}_y$) and technological characteristics ($\hat{\varepsilon}_{q_u}$), as one can see from the estimated parameters presented in Table 2. Moreover, since technical change only accounts for approximately 10% of TFP growth, adjustments for entry in and exit from the sample look as unimportant. However, the $\alpha(t)$ and $\beta(t)$ entry/exit parameters did bring some adjustments on the estimated index $A(t)$ in the additive specification and, therefore, on the estimated rate of technical change $\left(\dot{T}(E)\right)$.

To highlight the importance of these adjustments, we have computed in Table 4 the rates of technical change (using (18) for the three specifications considered). Like TFP growth rates, these are annual weighted averages. Results in Table 4 reveal that rates of technical change estimated with the multiplicative and the constrained specifications are quite similar. This is not surprising since none of the entry/exit adjustment parameters are statistically significant in the multiplicative specification. These rates are also much more volatile than the rates obtained with the additive specification, notably between 1987 and 1988 where unadjusted technical change is nearly 30% down! The corresponding rate obtained with the additive specification is more reasonable (-4.2%).

Results obtained with the additive specification show that trucking firms in Quebec have experienced a sharp decline in their rate of technical change since 1981. The only exception is in 1984–85 where the rate of technical change was positive. It is interesting to note that the first wave of deregulation in this industry (which has affected conditions of entry in the industry and, to a lesser extent, rate setting) occurred at that time. The second wave, which mainly concerns rates and safety, occurred in January 1988.

4.4 TFP Growth and Quality Changes

Between 1981 and 1988, the average length of haul grew at an annual rate of 2.1%, while the average shipment size, average load per truck and insurance for loss and damage grew respectively at 6.0%, 12.7% and -7.9%. Considering the important impact of technological characteristics on total costs, these changes suggest that firms altered their input choices, even when output levels remained constant. Therefore, observed TFP growth rates were influenced by variations of the technological characteristics.

Now, since the elasticities of costs with respect to output and technological characteristics are known, it is relatively easy to adjust the observed TFP growth for changes in characteristics. Table 5 presents these adjusted rates computed by equation (20) using the parameter estimates of the additive specification. The adjusted TFP growth is less volatile than the observed TFP growth. For instance, in 1984–85, the observed TFP growth is -15.9%, while the adjusted TFP growth is -4.5%. In 1987–88, the observed TFP growth is 63.4%, while the adjusted growth is decreasing at a rate of 4.6%. Overall, the adjusted TFP growth declined sharply during the period 1981–88. This result may seem surprising, but it is similar to the aggregate measure of productivity growth for the U.S. trucking industry during the same period (see table 15 in Gordon, 1991).

5. Concluding Comments

In this paper, we presented a methodology which can be applied for both estimating technical change with incomplete panel data and correcting observed TFP

growth rates for technological characteristics or output quality changes. Technical change rates have been estimated for a sample of Quebec's trucking firms. Our results show that firms not in the sample for the entire period studied are different in terms of the state of the technology they used, as measured by an estimated index of technological change. For instance, when entry in or exit from the sample is not explicitly controlled, the estimated rate of technical change between 1987 and 1988 is -29.7%. When entry in or exit from the sample is taken into account, the estimated rate is more credible at -4.2%.

Observed TFP growth rates have been adjusted for characteristic changes using the elasticities of costs with respect to technological characteristic variables. Hence, again in 1987–88, the observed TFP growth rate was 63.4%. After adjustment, the rate falls to -4.6%. Large differences between observed and adjusted TFP growth rates are explained by the important variations of network attributes experienced by the firms between 1981 and 1988. In turn, these variations may be explained by deregulation (notably in 1984–85 and 1987–88) and by cyclical variations of the demand.

Our methodology could be used to investigate the relationship between technical change and entry in or exit from the industry, particularly when these entry and exit movements follow important regulatory changes, as the ones observed in the airline industry.

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Table 1. Mean and Standard Deviation

Variable	Mean	Standard Deviation
C	11361002.79	21464175.79
w_1	0.41	0.08
w_2	29831.69	6975.66
w_3	1.03	0.91
w_4	6210.16	4184.02
y	84499.08	225726.69
q_1	398.78	227.54
q_2	4.90	5.55
q_3	0.045	0.055
q_4	0.002	0.006

Table 2. Parameter Estimates of the Total Cost Function

	Additive		Multiplicative		$\alpha(t) = \beta(t) = 0$	
Parameter	Estimate	t-ratio	Estimate	t-ratio	Estimate	t-ratio
a_0	17.0313	158.25	17.0264	157.69	16.9998	158.04
b_y	0.7303	14.67	0.8079	16.01	0.7609	14.79
c_1	0.0863	11.60	0.0785	9.43	0.0819	10.31
c_2	0.1891	14.56	0.2082	16.70	0.2121	17.11
c_3	0.3377	22.49	0.3118	25.80	0.3145	25.67
d_1	0.4467	4.53	0.3911	3.78	0.4335	4.05
d_2	0.7360	9.53	0.7216	9.57	0.6994	9.05
d_3	-0.4999	-6.08	-0.5328	-6.02	-0.4840	-5.09
d_4	0.2085	3.84	0.1748	3.33	0.1801	3.38
b_{yy}	-0.0129	-0.55	0.0008	0.04	-0.0128	-0.62
c_{11}	0.0478	13.10	0.0417	11.67	0.0443	12.34
c_{12}	-0.0031	-0.82	0.0026	0.70	0.0003	0.07
c_{13}	-0.0197	-6.92	-0.0189	-6.88	-0.0198	-7.14
c_{22}	0.0478	6.08	0.0516	6.56	0.0511	6.48
c_{23}	-0.0318	-4.83	-0.0364	-5.44	-0.0364	-5.43
c_{33}	0.0499	6.46	0.0526	6.55	0.0516	6.41
d_{11}	-0.1094	-1.03	-0.1364	-1.39	-0.1533	-1.54
d_{12}	0.0903	1.82	0.0416	0.95	0.0368	0.083
d_{13}	0.0606	1.08	0.0360	0.72	0.0272	0.54
d_{14}	-0.0238	-0.85	-0.0348	-1.30	-0.0300	-1.10
d_{22}	-0.0082	-0.16	-0.0086	-0.17	-0.0056	-0.11
d_{23}	-0.0847	-2.12	-0.0876	-2.22	-0.0861	-2.18
d_{24}	-0.0465	-1.98	-0.0474	-2.11	-0.0479	-2.10
d_{33}	0.2380	5.84	0.2113	5.96	0.1994	5.53
d_{34}	0.0287	1.11	0.0053	0.21	0.0121	0.46
d_{44}	0.0099	0.68	0.0047	0.32	0.0096	0.65
f_{y1}	0.0055	1.87	0.0007	0.24	0.0034	1.18
f_{y2}	0.0114	2.37	0.0060	1.21	0.0087	1.78
f_{y3}	0.0020	0.41	0.0030	0.64	0.0053	1.15
g_{y1}	0.0449	1.16	0.0307	0.92	0.0381	1.12
g_{y2}	-0.0507	-1.85	-0.0275	-1.06	-0.0323	-1.25
g_{y3}	-0.1113	-4.10	-0.1101	-4.63	-0.0988	-4.23
g_{y4}	-0.0267	-1.65	-0.0143	-0.95	-0.0131	-0.86
h_{11}	-0.0135	-2.43	-0.0094	-1.74	-0.0112	-2.08
h_{21}	-0.0875	-9.61	-0.0807	-8.60	-0.0836	-9.03
h_{31}	0.0410	4.73	0.0363	4.07	0.0341	3.84

Table 2. (Continued) Parameter Estimates of the Total Cost Function

	Additive		Multiplicative		$\alpha(t) = \beta(t) = 0$	
Parameter	Estimate	t-ratio	Estimate	t-ratio	Estimate	t-ratio
h_{12}	0.0124	2.96	0.0104	2.54	0.0115	2.82
h_{22}	0.0003	0.05	-0.0002	-0.02	0.0004	0.06
h_{32}	0.0124	1.89	0.0121	1.80	0.0133	1.98
h_{13}	-0.0263	-5.55	-0.0220	-4.65	-0.0233	-4.95
h_{23}	-0.0236	-3.04	-0.0228	-2.80	-0.0238	-2.96
h_{33}	-0.0024	-0.31	-0.0033	-0.42	-0.0044	-0.56
h_{14}	-0.0150	-5.52	-0.0148	-5.53	-0.0143	-5.35
h_{24}	-0.0150	-3.33	-0.0150	-3.20	-0.0140	-3.03
h_{34}	0.0084	1.97	0.0070	1.58	0.0075	1.70
$A(82)$	-0.1158	-1.36	-0.2420	-2.02	-0.1942	-1.68
$A(83)$	-0.3239	-2.34	-0.2326	-2.00	-0.1898	-1.68
$A(84)$	-0.1839	-1.82	-0.2232	-1.88	-0.1619	-1.55
$A(85)$	-0.2190	-2.03	-0.1794	-1.77	-0.1607	-1.59
$A(86)$	-0.2017	-1.96	-0.1220	-1.44	-0.1193	-1.41
$A(87)$	-0.1648	-1.72	-0.1431	-1.58	-0.1364	-1.49
$A(88)$	-0.0936	-1.19	0.0581	0.81	0.0562	0.90
ϕ_y	-0.2106	-1.23	-0.1560	-0.83	-0.3414	-1.11
ψ_1	-0.0506	-2.68	-0.0998	-3.23	-0.0994	-2.59
ψ_2	-0.1249	-2.60	0.0147	0.27	0.0373	0.53
ψ_3	0.2198	2.32	0.0633	1.10	0.0903	1.16
μ_1	0.4835	1.74	0.9364	1.97	1.2725	1.75
μ_2	0.2641	1.49	0.0188	0.08	-0.0772	-0.24
μ_3	0.5967	1.95	0.8659	1.84	1.2856	1.64
μ_4	0.4233	2.75	0.2273	1.69	0.2604	1.52
$\alpha(82)$	-0.1711	-1.61	0.0320	0.97	- -	- -
$\alpha(83)$	0.1038	0.91	0.0332	0.82	- -	- -
$\alpha(84)$	0.0473	0.38	0.0421	0.79	- -	- -
$\alpha(85)$	0.2378	1.95	0.0119	0.28	- -	- -
$\alpha(86)$	-0.1570	-1.13	0.0423	0.46	- -	- -
$\alpha(87)$	0.0186	0.20	0.1673	1.46	- -	- -
$\beta(82)$	-0.0777	-0.56	-0.0641	-0.97	- -	- -
$\beta(83)$	0.2446	1.87	0.0342	0.85	- -	- -
$\beta(84)$	-0.1901	-1.45	0.1091	1.48	- -	- -
$\beta(85)$	-0.1280	-1.15	-0.0119	-0.20	- -	- -
$\beta(86)$	0.1882	1.82	0.0042	0.08	- -	- -
$\beta(87)$	-0.4824	-2.22	0.1142	0.95	- -	- -

Table 2. (Continued) Parameter Estimates of the Total Cost Function

	Additive	Multiplicative	$\alpha(t) = \beta(t) = 0$
$\log(L)$	1859.3253	1857.8719	1849.4968
R^2 (adjusted)	0.74	0.73	0.74
No. of par.	72	72	60
No. of obs.	269	269	269

Note: First-order parameters and technical change indexes $A(t)$ are statistically different from zero when the t-ratio is greater than 1.282 (one tail-test at a confidence level of 10%). The corresponding critical value for the other parameters is 1.645 (two-tail test).

Table 3. Observed and Estimated TFP Growth
Annual Averages

	Observed		Estimated (incomplete panel data)		
Year	Incomplete	Complete	Additive	Multiplicative	$\alpha(t) = \beta(t) = 0$
1981-82	-0.062	-0.349	-0.103	0.098	0.018
1982-83	-0.221	0.044	-0.162	-0.129	-0.131
1983-84	-0.107	0.051	0.009	0.034	0.031
1984-85	-0.159	-0.074	-0.100	-0.134	-0.113
1985-86	0.118	-0.090	0.100	0.075	0.092
1986-87	0.170	0.081	0.201	0.238	0.237
1987-88	0.634	0.344	0.817	0.645	0.658

Table 4. Technical Change Estimates
Annual Averages

Year	Additive	Multiplicative	$\alpha(t) = \beta(t) = 0$
1981-82	-0.033	0.157	0.087
1982-83	-0.028	-0.006	-0.002
1983-84	-0.039	-0.005	-0.012
1984-85	0.014	-0.028	-0.001
1985-86	-0.008	-0.043	-0.028
1986-87	-0.023	0.019	0.017
1987-88	-0.042	-0.263	-0.297

Table 5. Adjusted TFP Growth Rates
Annual Averages

Year	$\dot{TFP}^*(E)$
1981-82	-0.002
1982-83	-0.081
1983-84	-0.139
1984-85	-0.045
1985-86	0.032
1986-87	-0.015
1987-88	-0.046